PROPERTIES OF SHOCKED AEROGEL. W.W. Anderson, Department of Geology and Physics, Georgia Southwestern State University, Americus, GA 31709; bill@gsw1500.gsw.peachnet.edu.

A wide range of ultra-low density media have been considered for use in capturing interplanetary dust particles (IDP's). Most recent work has concentrated on silica aerogel as the capture medium. Only within the past few years, however, has a sizable set of data on the behavior of aerogel under shock compression become available. These data can be used as a starting point in developing models for the properties of shocked aerogel that are necessary for understanding the behavior of IDP impacts into aerogel.

The pressure, density, and internal energy in a shocked material are given by

$$P_H - P_0 = \rho_{00} U_s u_p$$

$$\rho_H = \rho_{00} U_s \big/ \left(U_s - u_p\right)$$

$$E_H - E_0 = P\left(V_{00} - V_H\right)\big/2 = u_p^2 \big/ 2$$

where $V = 1/\rho$ is the specific volume and U_s and u_p are the speed of the shock wave and shock material, respectively, in the rest frame of the unshocked material. The subscript 00 denotes the porous material while the subscripts 0 and H refer to the initial state and the condition on the Hugoniot curve. It is common to assume that P_0 and E_0 are zero.

The shock wave velocity, U_s, is often expressed as a linear function of the particle velocity, u_p:

$$U_s = C_0 + s u_p$$

where C_0 and s are empirical constants. The shock Hugoniot curves of many materials consist of two or more such straight line segments, reflecting changes in behavior that result from phase changes. Data now exist for a range of aerogel densities [1-5], giving rise to the shock Hugoniot curves shown in Figure 1. At the scale of Figure 1, all the Hugoniot curves fall close to one another. Figure 2 shows the curves at an expanded scale. The data, covering a wide range of conditions, suggest a general qualitative model of the aerogel Hugoniot curve that consists of straight line segments, with a slight break in slope occurring in the region $u_p \approx 4$ km/s. The values of C_0 and s can be expressed as functions of the initial density ρ_{00}, with

$$C_0 = .436 - 2.024 \rho_{00} + 4.18 \rho_{00}^2$$

$$s = 0.700 + 24.4 \rho_{00} - 36.3 \rho_{00}^2$$

at low velocity and

$$C_0 = -0.947 + 1.78 \rho_{00}$$

$$s = 1.201 + 0.824 \rho_{00}$$

at high velocity, where C_0 is expressed in km/s and ρ_{00} is expressed in Mg/m^3.

Examination of P-V curves calculated from the U_s-u_p relations shows that, just above the break in slope, the density begins to decrease with increasing shock pressure. Both the break in the U_s-u_p curve and the occurrence of a density minimum at similar shock conditions is probably the result of bond breakage. This bond breakage should have a significant effect on the temperature and viscosity of the shocked aerogel.

Estimation of the temperature in the shock-compressed state requires us to account for both the bond breakage and the compression process. The total energy can be divided into a cold compression part, a thermal part, and a configurational part (which includes the energy that goes into rupturing bonds). For calculating the temperature, we are interested in the thermal part. Usually, the thermal energy is estimated is by subtracting the other components of the energy from the total.

We can approximate the cold compression part of the energy by assuming isentropic compression from STP to the volume of interest, after taking the bond breakage into account. For very porous starting materials, we can usually expect to find that the cold compression energy is relatively small.

Most of the configurational energy change, which we will call the transition energy, E_{tr}, consists of energy required to disrupt chemical bonds. In the case of SiO$_2$, the bond strength per mole of SiO$_2$, calculated from the enthalpy of formation and bond strengths of the elements in their standard states, is 1.852 MJ/mol (30.9 MJ/kg). This is the decomposition energy. The equilibrium constant for complete decomposition can be approximated as

$$K = x_{Si} x_O^2 \big/ x_{SiO_2} = 4 x_r^3 \big/ \left(1 - x_r\right) \approx e^{-3 E_B / E_{th}}$$

where E_B is the bond energy per unit of mass and E_{th} is the thermal part of the shock energy. The factor of 3 in the exponential reflects the spatial degrees of freedom in the system. The advantage of casting the equilibrium constant in this form is that it does not require prior knowledge of the temperature. The actual amount of reaction x is given by

$$x = x_r e^{-\tau / t}$$

where τ is the time constant for the reaction and t is the time available for the reaction. In the case of a bow shock wave in front of an IDP, this is the time required between arrival of the shock wave and the arrival of the front surface of the particle. The transition energy is then given by

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$$E_{tr} = xE_B$$

We can estimate the temperature of shocked aerogel for comparison with experiments by using the equilibrium value of x and assuming that the cold compression energy is negligible. The temperature then is given by

$$T \approx (E_H - E_{tr})/C_V$$

Here, we use the Dulong-Petite limit for the specific heat C_V. For aerogel with $\rho_{00} = 0.13$ Mg/m^3 for $u_p = 6.56$ km/s, we get $T = 11400$ K, which compares to an experimental value of 10800 ± 1200 K [1].
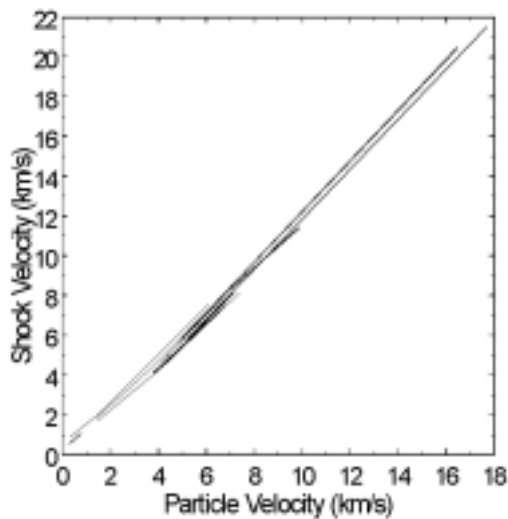
References:
[1] Holmes, N. C., H. B. Radousky, M. J. Moss, W. J. Nellis, and S. Henning, *Appl. Phys. Lett., 45*, 626-628, 1984.
[2] Simakov, G. V., and R. F. Trunin, *Izv. Earth Physics, 26*, 952-956, 1990.
[3] Rabie, R., and J. J. Dick, in *Shock Compression of Condensed Matter 1991*, 87-90, 1992.
[4] Holmes, N. C., and E. F. See, in *Shock Compression of Condensed Matter 1991*, 91-94, 1992.
[5] Vildanov, V. G., M. M. Gorshkov, V. M. Slobodenjukov, and E. H. Rushkovan, in *Shock Compression in Condensed Matter - 1995*, 121-124, 1996.

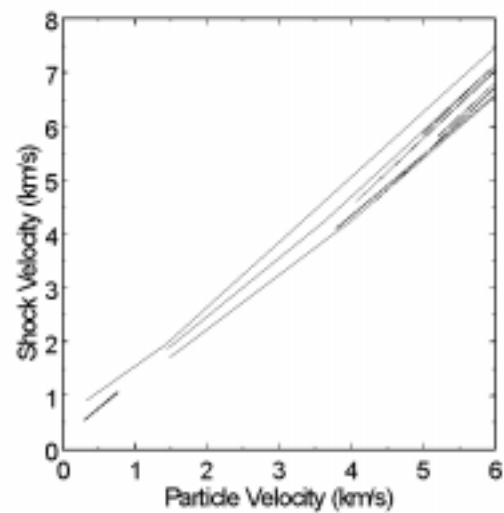Figure 1. Experimental Hugoniots for aerogel with ρ_{00} in the range from 0.13 Mg/m^3 to 0.55 Mg/m^3.

Figure 2. Expanded view of Hugoniot curves presented in Figure 1. Typically, the higher values of ρ_{00} correspond to the curves positioned higher in the graph.